British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Estimating groundwater recharge for Great Britain

Lei Wang
British Geological Survey

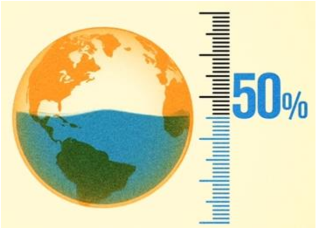
Xueliang Mu, Yuepeng Hu, Weibin Lin, Rongmeihui Zheng
University of Nottingham

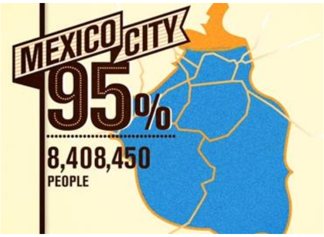
29th November 2014

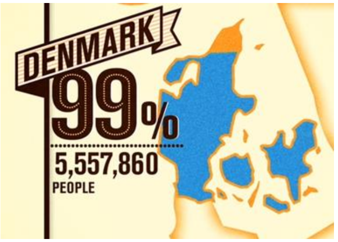
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Background

- Groundwater provides a third of our drink water in Great Britain (up to 80% of water supply in Southern England)







- Groundwater also maintains many rivers and wetlands
- Recharge determines how much water (and soluble pollutants) entering the groundwater system
- Recharge estimate is important for supporting sustainable water resource management
- It is necessary to develop a national groundwater recharge model for Great Britain

Methodologies

❖ Recharge calculation methods:

- ➢ Tracer
- ➢ Lysimeter
- ➢ Water table fluctuation
- ➢ Unsaturated flow equation
- ➢ Soil water balance

} Short estimation time periods or expense encountered in parameter value estimation.

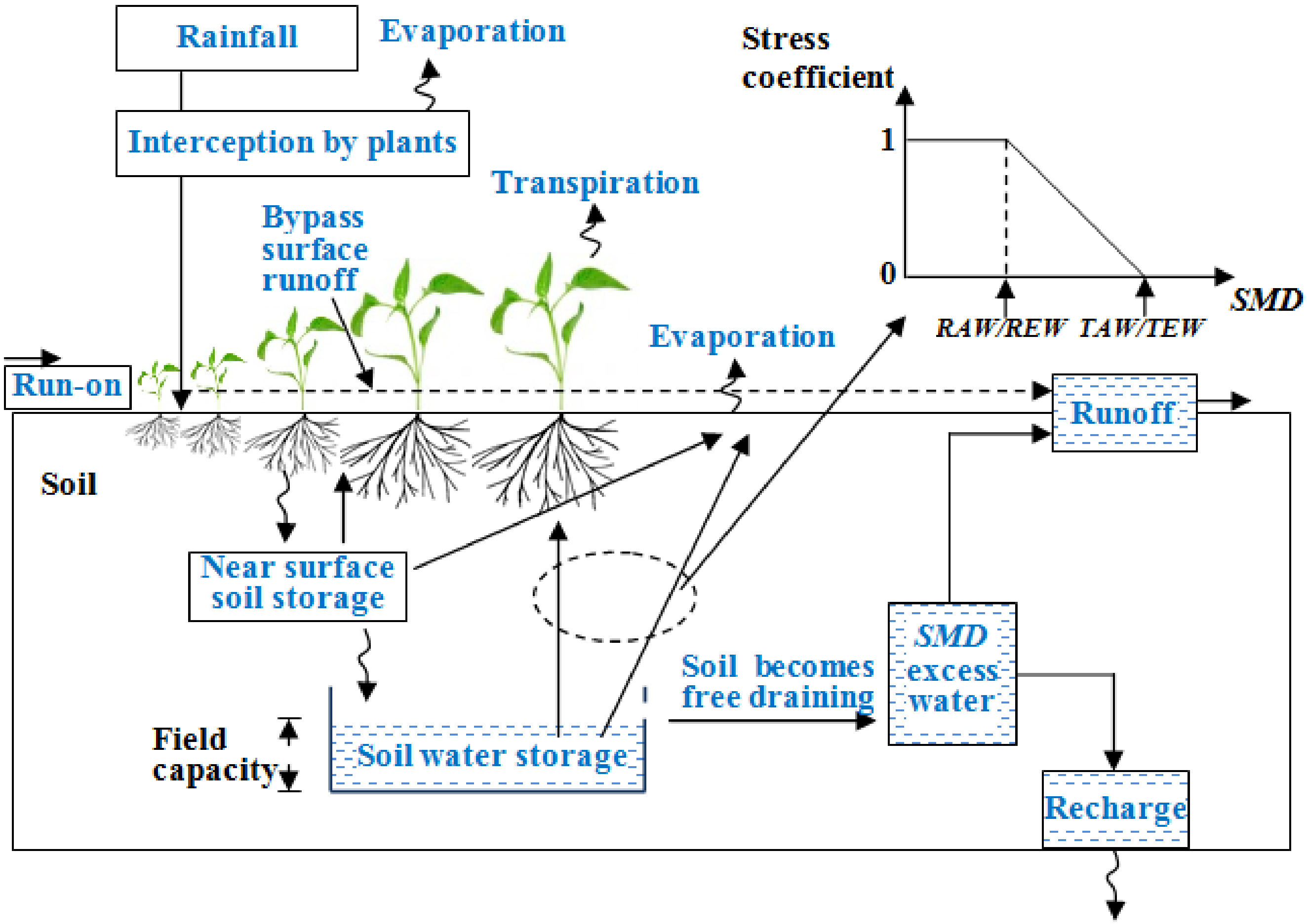
Carefully designed soil water balance methods are powerful in estimating recharge

- o Removes runoff before calculating soil moisture and hence the actual evapotranspiration
- o Estimate runoff subjectively based on amount of rainfall and antecedent soil moisture deficit (Eilers et al., 2007)

Runoff coefficients at specific rainfall intensities and soil moisture deficits

SMD at start of day (mm)	Rainfall intensity (mm/d)				
	0	20	40	60	80
0	0.10	0.15	0.30	0.45	0.70
20	0.07	0.10	0.25	0.40	0.60
50	0.00	0.05	0.20	0.35	0.55
100	0.00	0.02	0.10	0.20	0.40

SLiM method for estimating runoff and recharge



SLiM method for estimating runoff and recharge

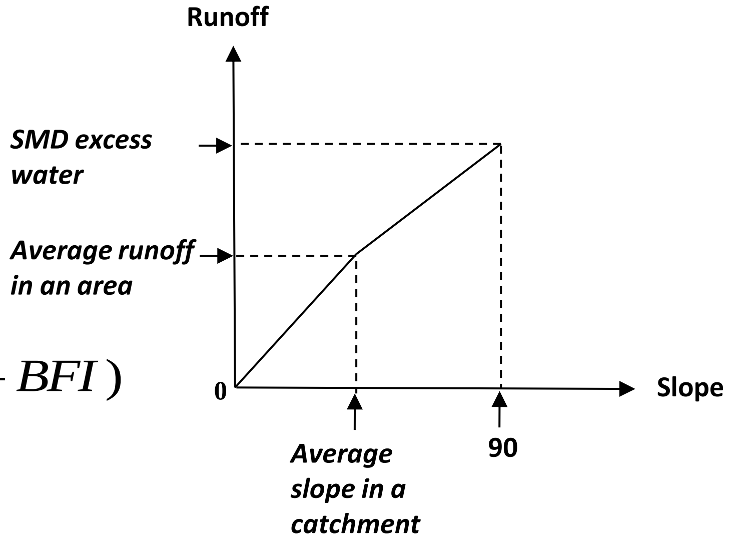
- **SMD excess water**

$$Ro = \frac{E_{SMD} \cdot (1 - BFI) \cdot Slp}{Slp_{mean}} \qquad Slp \leq Slp_{mean}$$

$$Ro = \frac{(Slp - Slp_{mean}) \cdot E_{SMD} \cdot BFI}{(90 - Slp_{mean})} + E_{SMD} \cdot (1 - BFI)$$

$$Slp_{mean} < Slp < 90$$

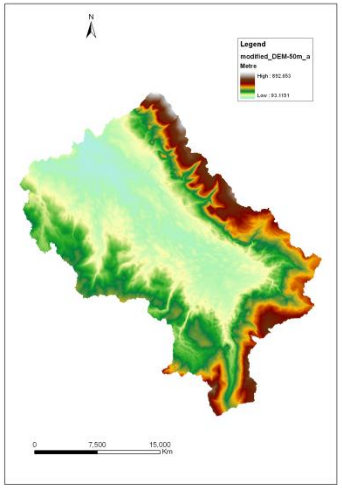
$$RECH = E_{SMD} - Ro$$



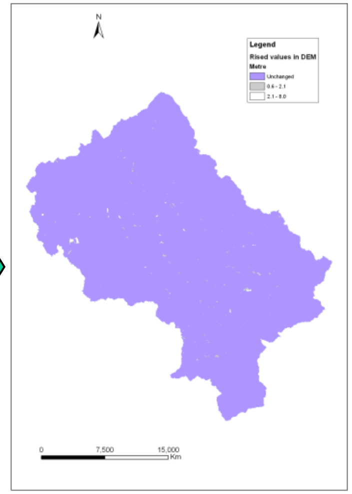
- **Bypass runoff**

Both runoff and recharge are objectively linked to rainfall intensity, potential evapotranspiration, topography, soil type, crop type and BFI

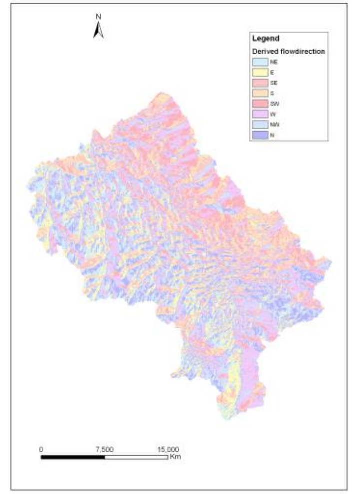
SLiM code



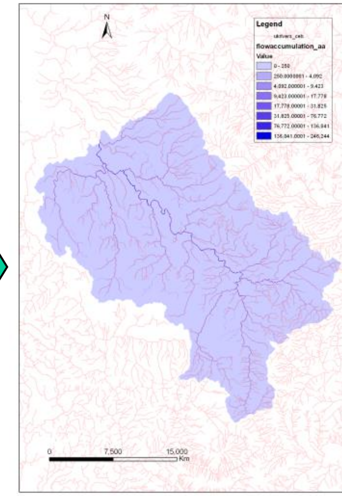
Original DEM



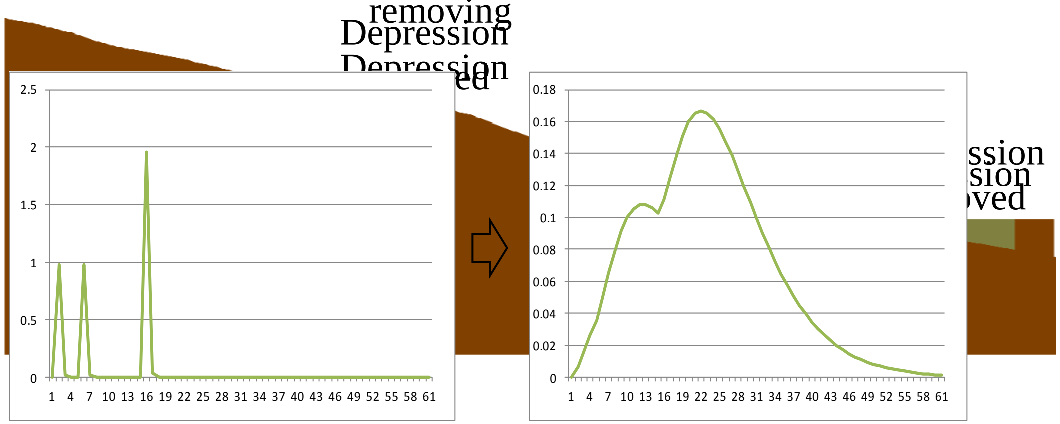
Auto depression (pond) removing

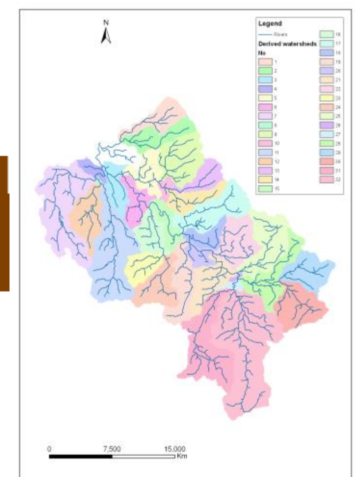


Deriving flow direction



Flow accumulation



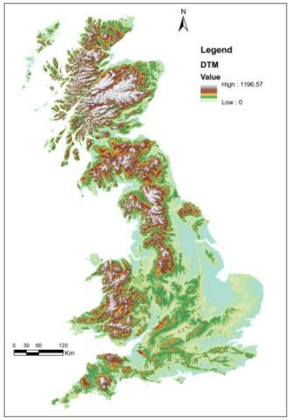


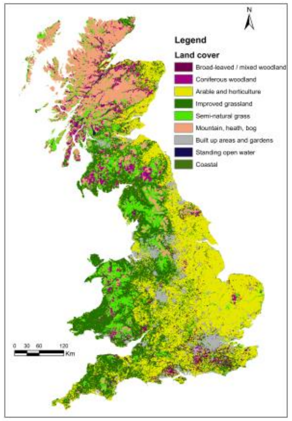
$$Ro_{dis}^{t} = (Ro^{t} + Ro_{stor}^{t-1}) \cdot \left\{ 1 - \exp\left[\frac{-C_{lag}}{T} \right] \right\}$$

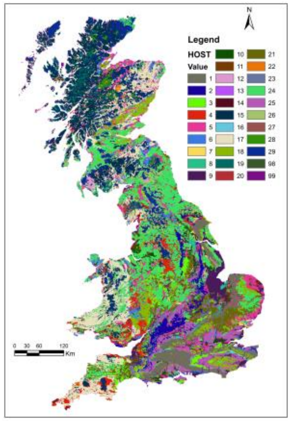
Delineating watersheds

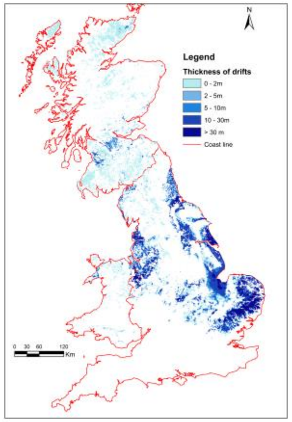
Datasets for national recharge modelling

- Digital Terrain Model (DTM)
- Daily distributed rainfall
- Potential evapotranspiration
- Land-cover
- Hydrology of soil types (HOST)
- The thickness of low permeability superficial deposit
- River flow from 102 gauging stations across Great Britain





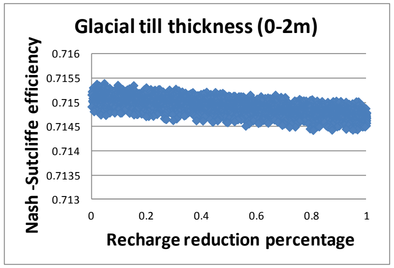


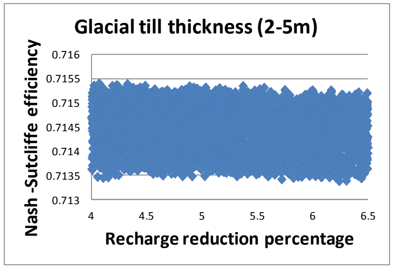


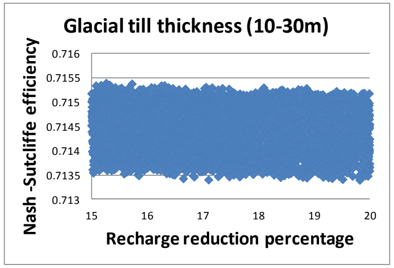
Model Construction

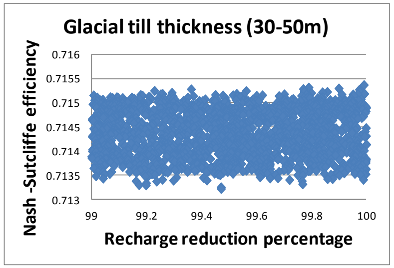
- Spatial resolution: 1km by 1km (229,619 km^2)
- Time step: daily (1962-2011)
- Catchment area for 102 gauging stations
- Low permeability superficial deposition recharge reduction:

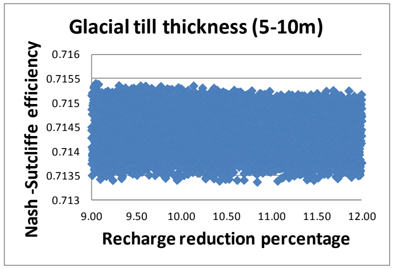
0-2m: 0.095%;
2-5m: 4.226%
5-10m:9.066%;
10-30m:15.323%
30-50m: 99.991%











Model Calibration

- The manual calibration was carried by comparing the modelled and observed river flows for each river gauging station;
- Monthly rainfall interception and lag coefficient were mainly used for calibration;
- Nash-Sutcliffe efficiency (*NSE*) was used to measure the goodness-of-fit between the modelled and observed values, in the conjunction with visual inspection.

$$NSE = 1 - \frac{\sum_{i=1}^{N} (Vobs_i - Vsim_i)^2}{\sum_{i=1}^{N} (Vobs_i - \overline{Vobs})^2}$$

NSE>0.5 means good match between modelled and observed values

Calibration: lag coefficient

- The time lag and amount of run-off stored in overland and stream flow can be expressed using an exponential function of water travel time in one cell with a runoff lag coefficient

$$Ro_{dis}^{t} = (Ro^{t} + Ro_{stor}^{t-1}) \cdot \left\{ 1 - \exp\left[\frac{-C_{lag}}{T} \right] \right\}$$

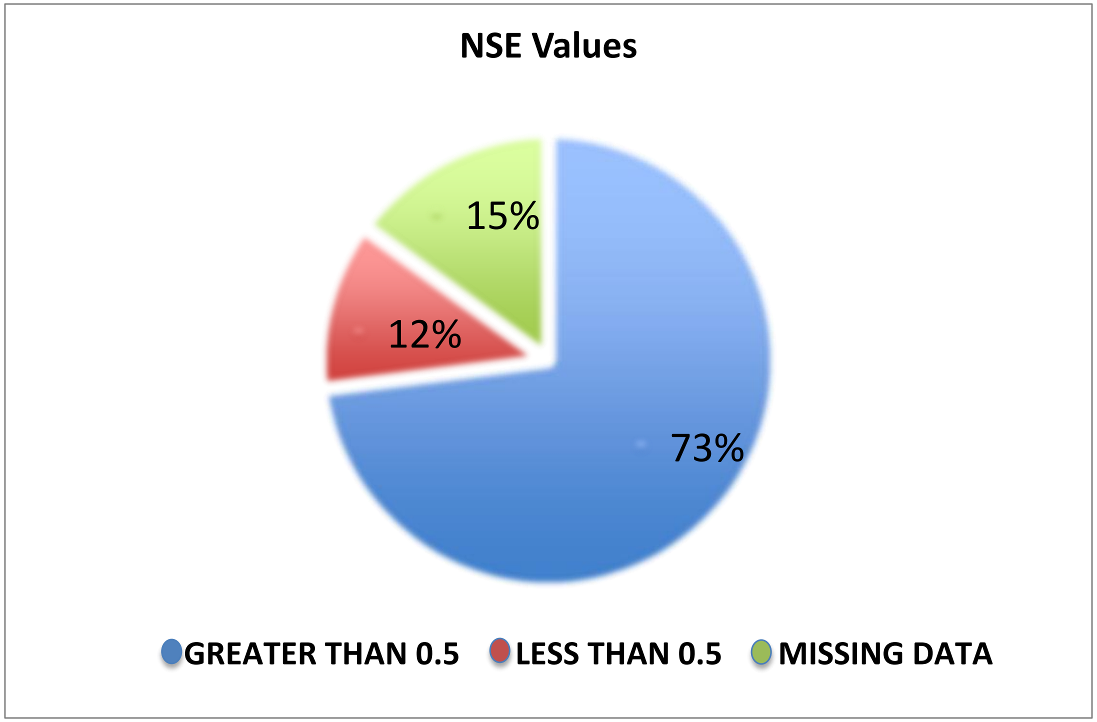
- Its value reflects the roughness of a area. Higher roughness mean slower water movement on ground surface.

Calibration: interception coefficient

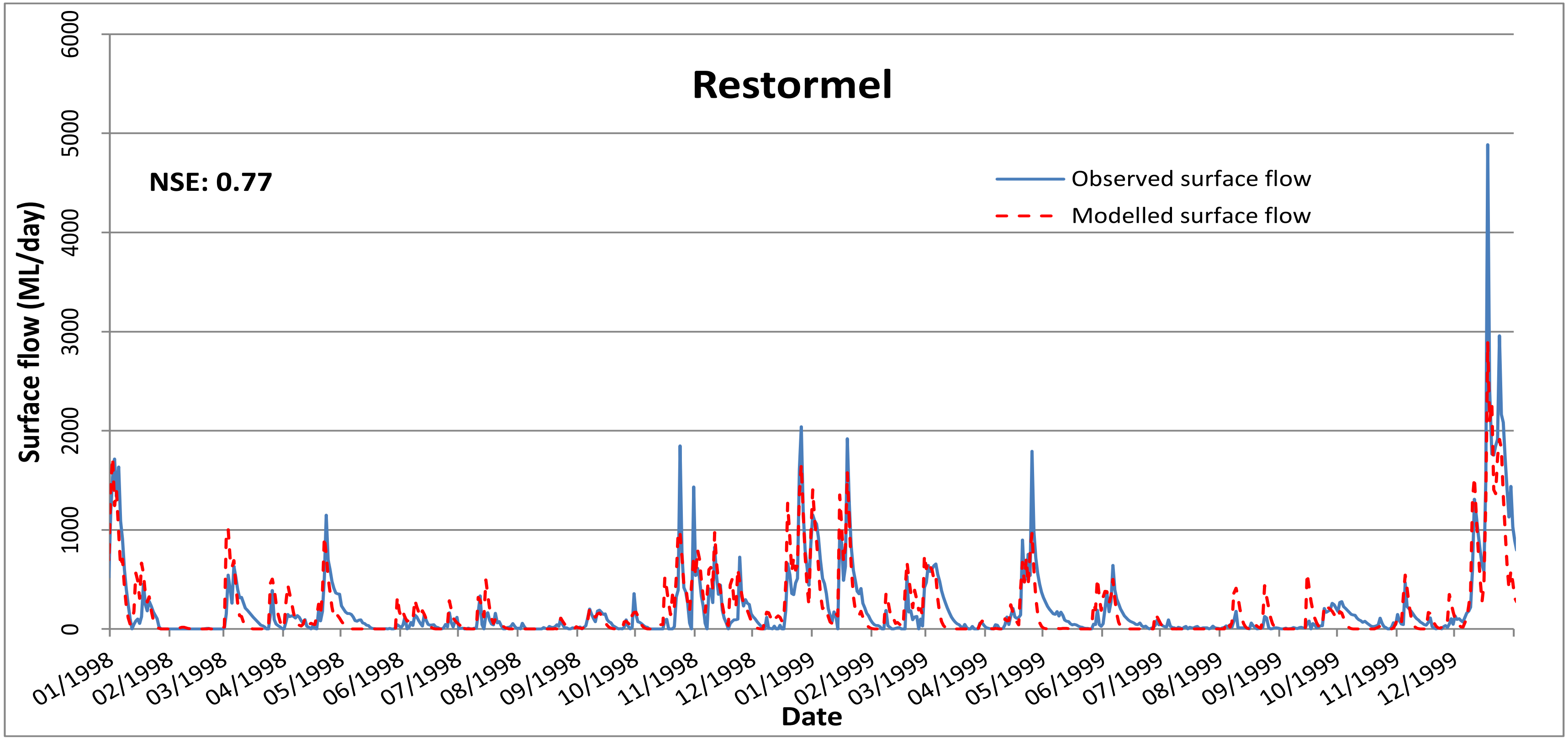
- Rainfall interception is amount of water that is intercepted by plants, and will not reach the soil
- This parameter reflects the change of land cover in different seasons for one catchment

Results

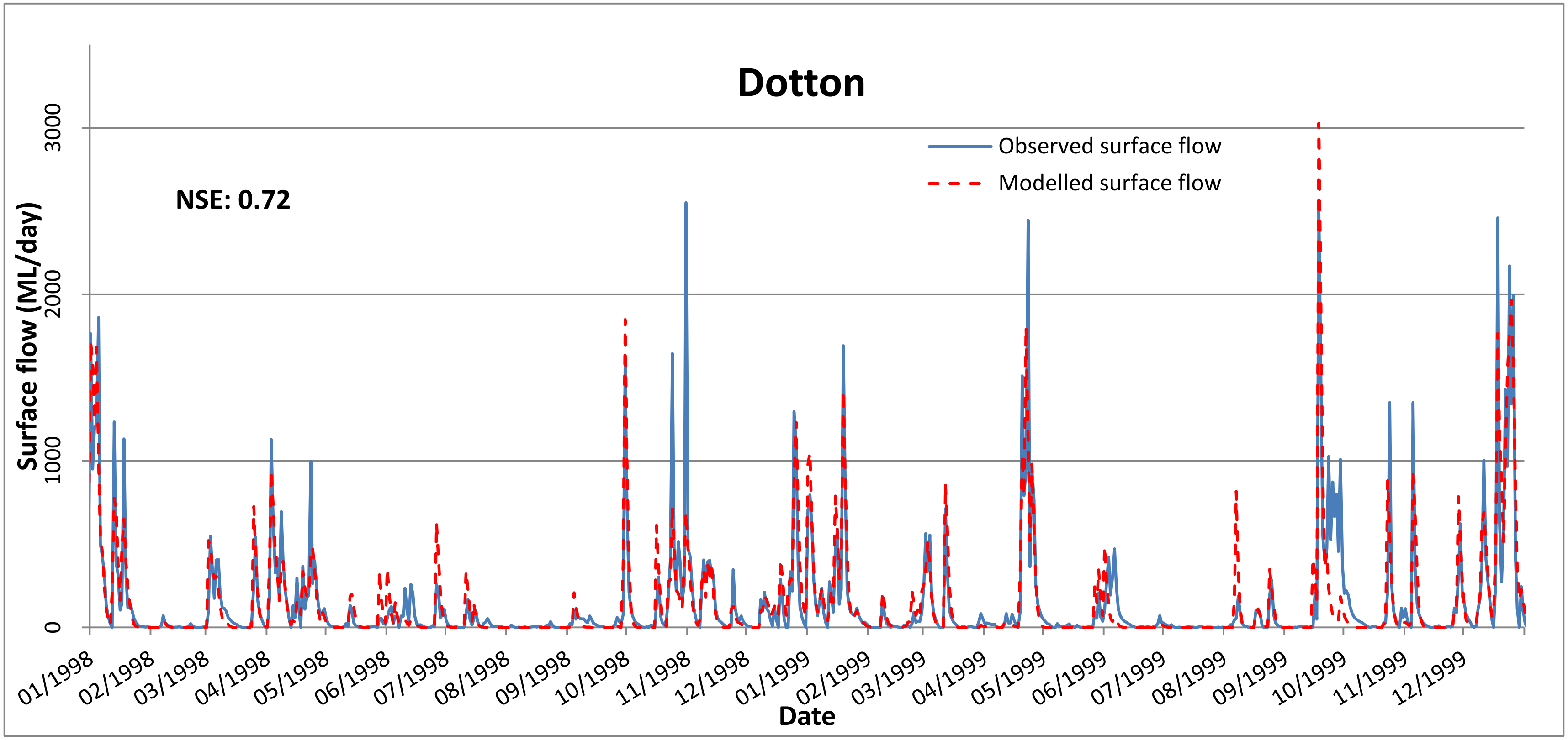
After calibration, 73% of gauging stations have *NSE* > 0.5, which gives acceptable model performance.
It needs to bare in mind this an application of a simple model at the national scale; and it is acceptable that 12% of results have *NSE*<0.5.



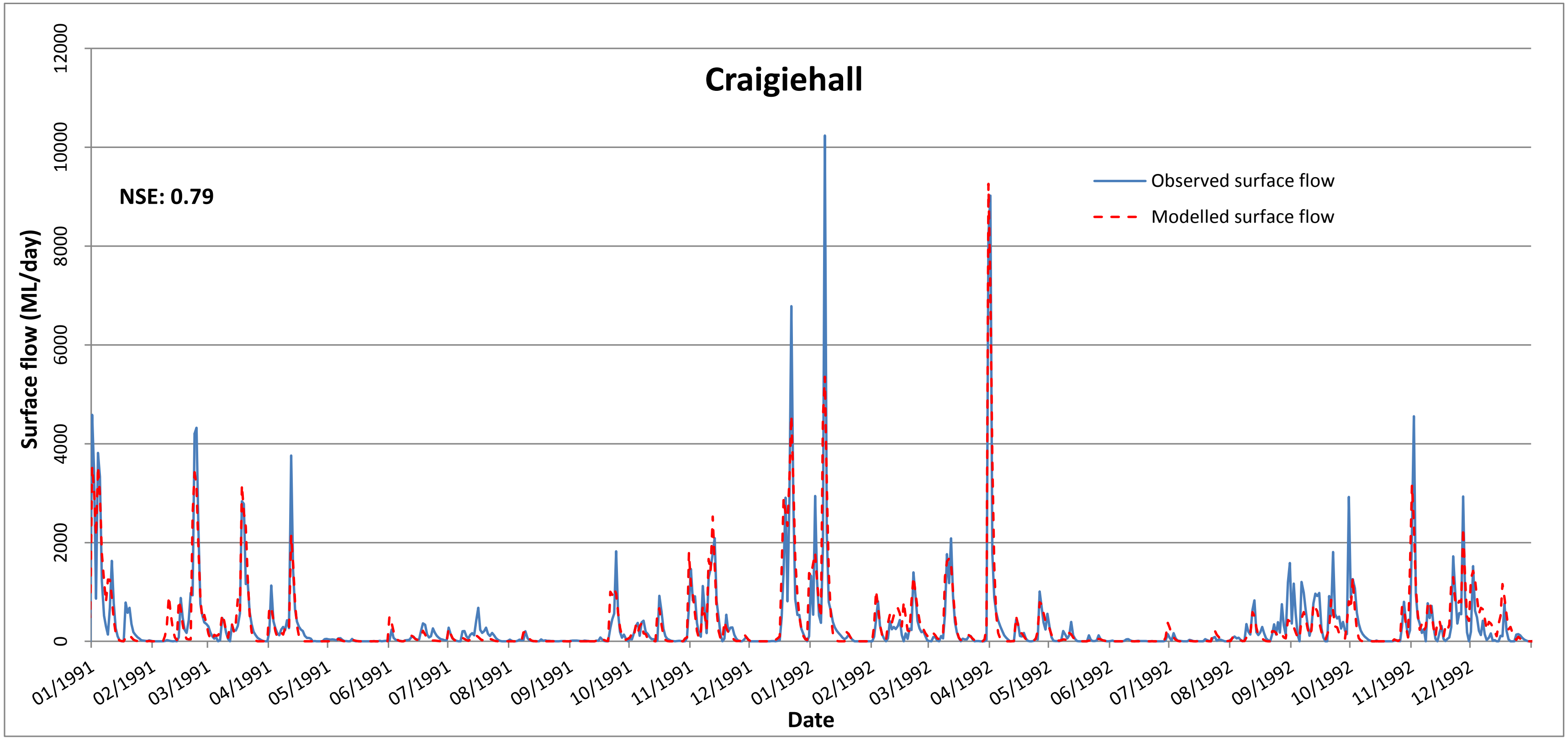
Results


Restormel
NSE: 0.77
Observed surface flow
Modelled surface flow
Surface flow (ML/day)
0
1000
2000
3000
4000
5000
6000
01/1998
02/1998
03/1998
04/1998
05/1998
06/1998
07/1998
08/1998
09/1998
10/1998
11/1998
12/1998
01/1999
02/1999
03/1999
04/1999
05/1999
06/1999
07/1999
08/1999
09/1999
10/1999
11/1999
12/1999
Date

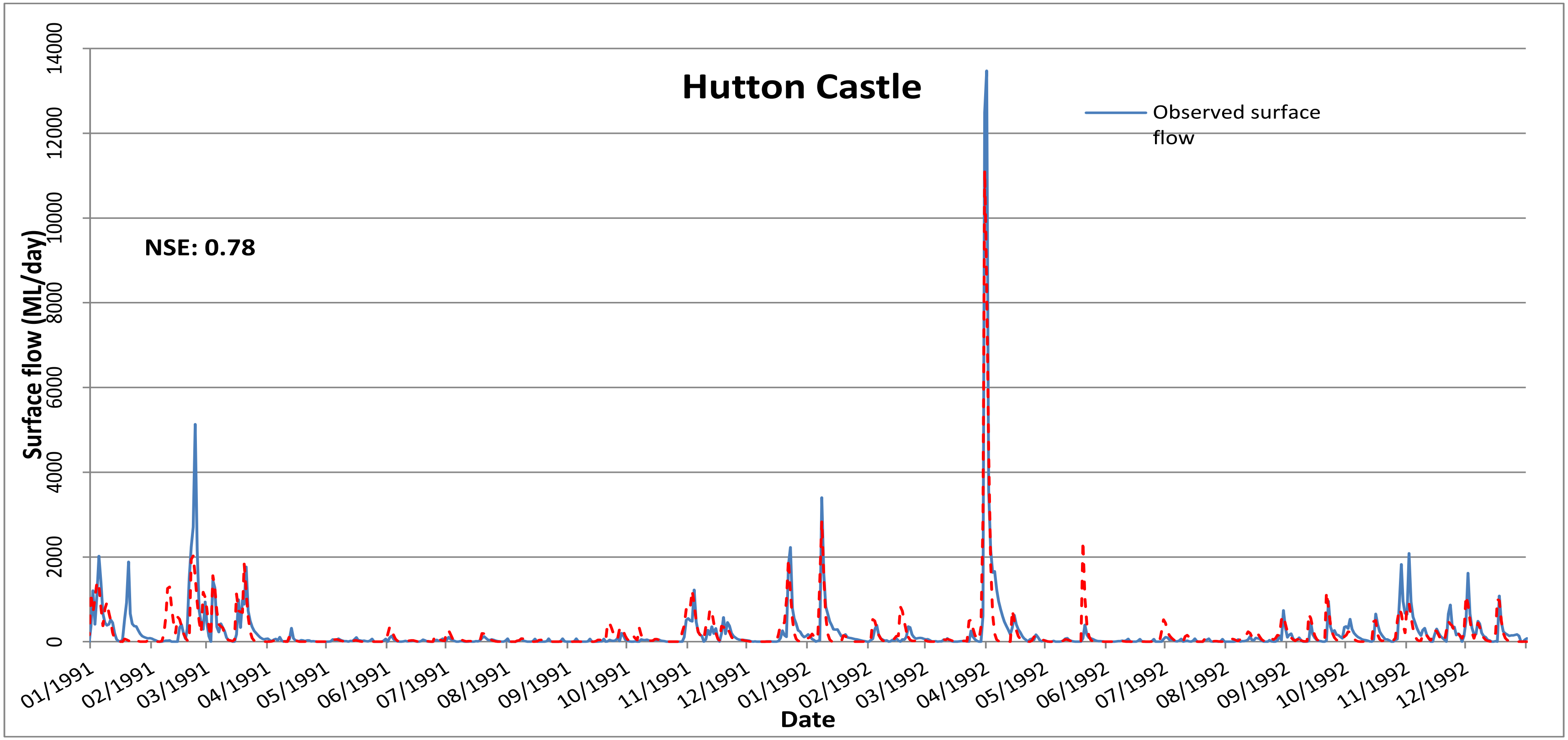
Results


Dotton
NSE: 0.72
Observed surface flow
Modelled surface flow
Surface flow (ML/day)
0
1000
2000
3000
Date
01/1998
02/1998
03/1998
04/1998
05/1998
06/1998
07/1998
08/1998
09/1998
10/1998
11/1998
12/1998
01/1999
02/1999
03/1999
04/1999
05/1999
06/1999
07/1999
08/1999
09/1999
10/1999
11/1999
12/1999

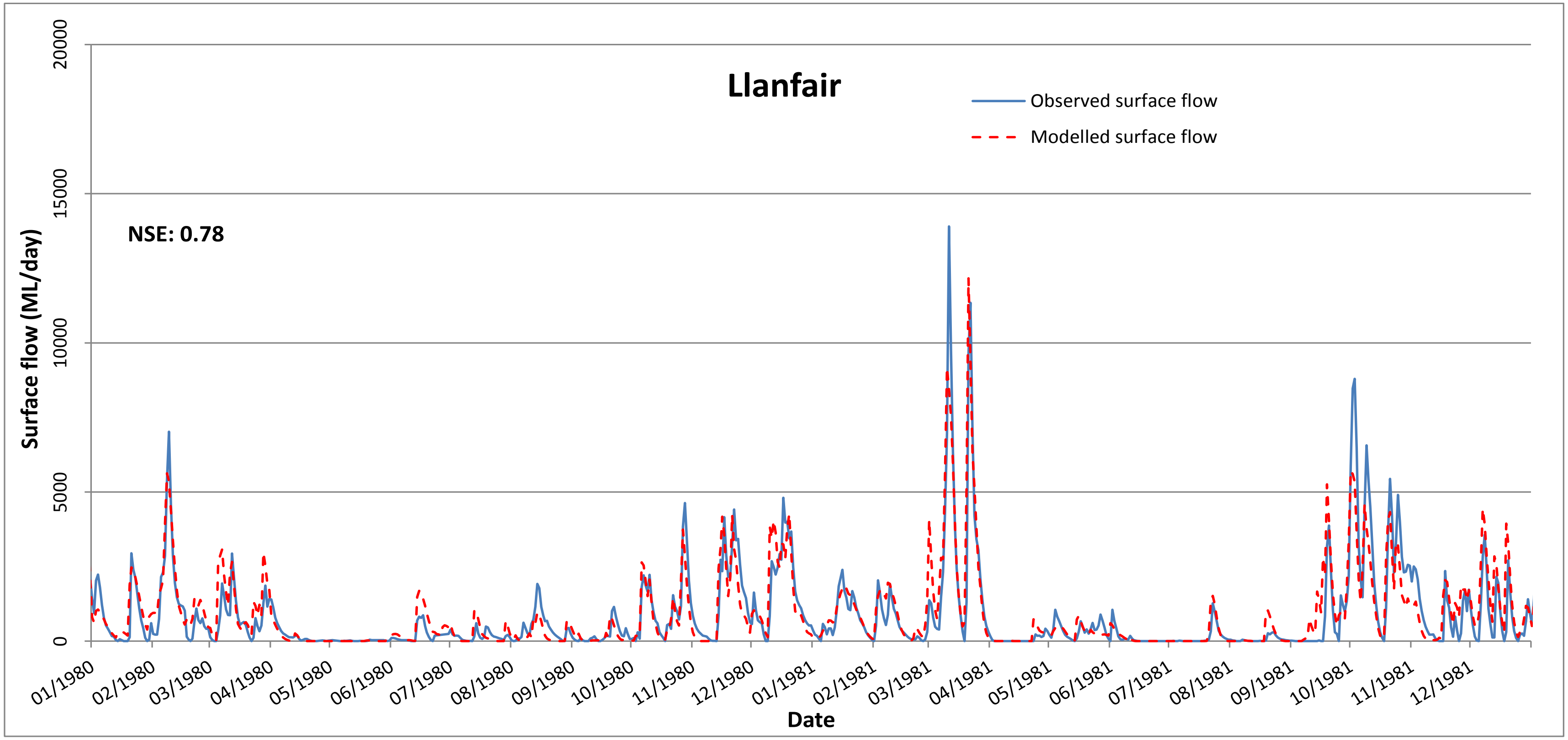
Results


Craigiehall
NSE: 0.79
Observed surface flow
Modelled surface flow
Surface flow (ML/day)
0
2000
4000
6000
8000
10000
12000
Date
01/1991
02/1991
03/1991
04/1991
05/1991
06/1991
07/1991
08/1991
09/1991
10/1991
11/1991
12/1991
01/1992
02/1992
03/1992
04/1992
05/1992
06/1992
07/1992
08/1992
09/1992
10/1992
11/1992
12/1992

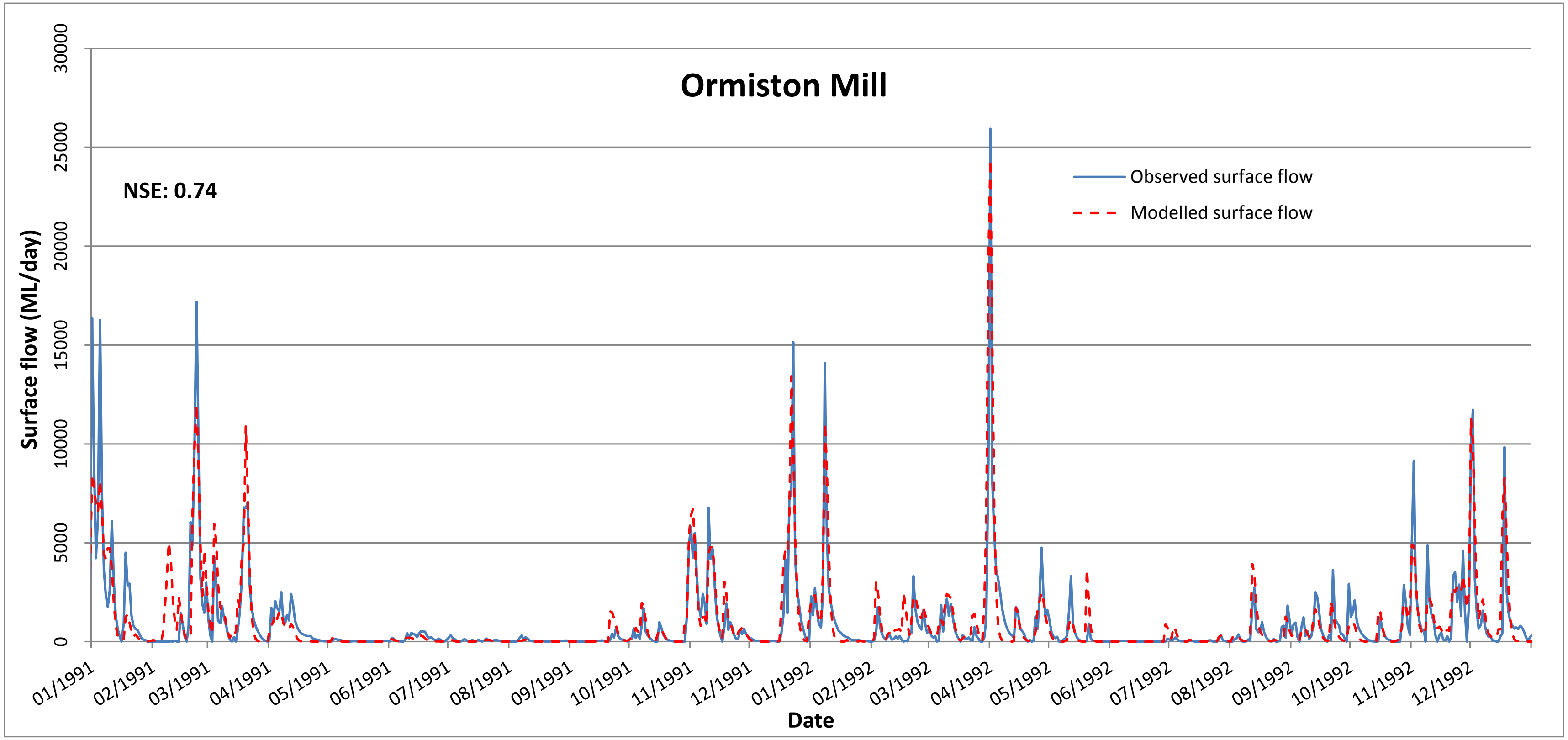
Results


Hutton Castle
Observed surface flow
NSE: 0.78
Surface flow (ML/day)
0
2000
4000
6000
8000
10000
12000
14000
01/1991
02/1991
03/1991
04/1991
05/1991
06/1991
07/1991
08/1991
09/1991
10/1991
11/1991
12/1991
01/1992
02/1992
03/1992
04/1992
05/1992
06/1992
07/1992
08/1992
09/1992
10/1992
11/1992
12/1992
Date

Results


Llanfair
Observed surface flow
Modelled surface flow
NSE: 0.78
Surface flow (ML/day)
0
5000
10000
15000
20000
01/1980
02/1980
03/1980
04/1980
05/1980
06/1980
07/1980
08/1980
09/1980
10/1980
11/1980
12/1980
01/1981
02/1981
03/1981
04/1981
05/1981
06/1981
07/1981
08/1981
09/1981
10/1981
11/1981
12/1981
Date

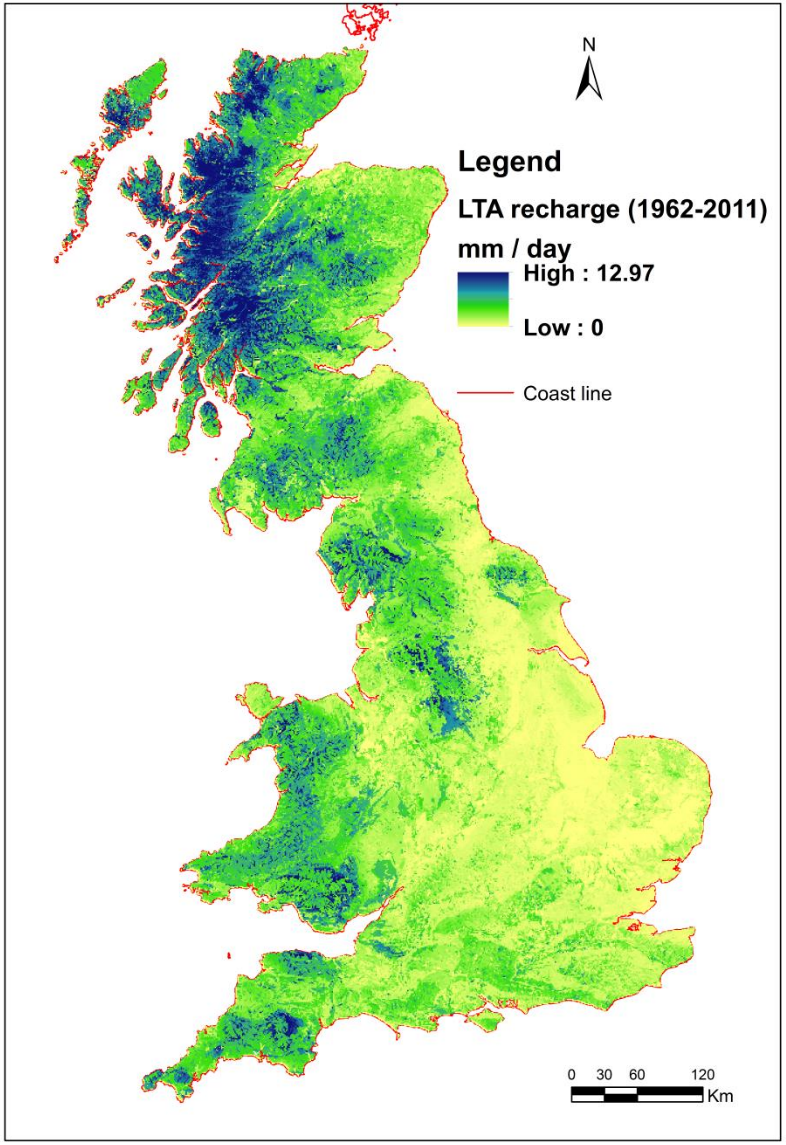
Results



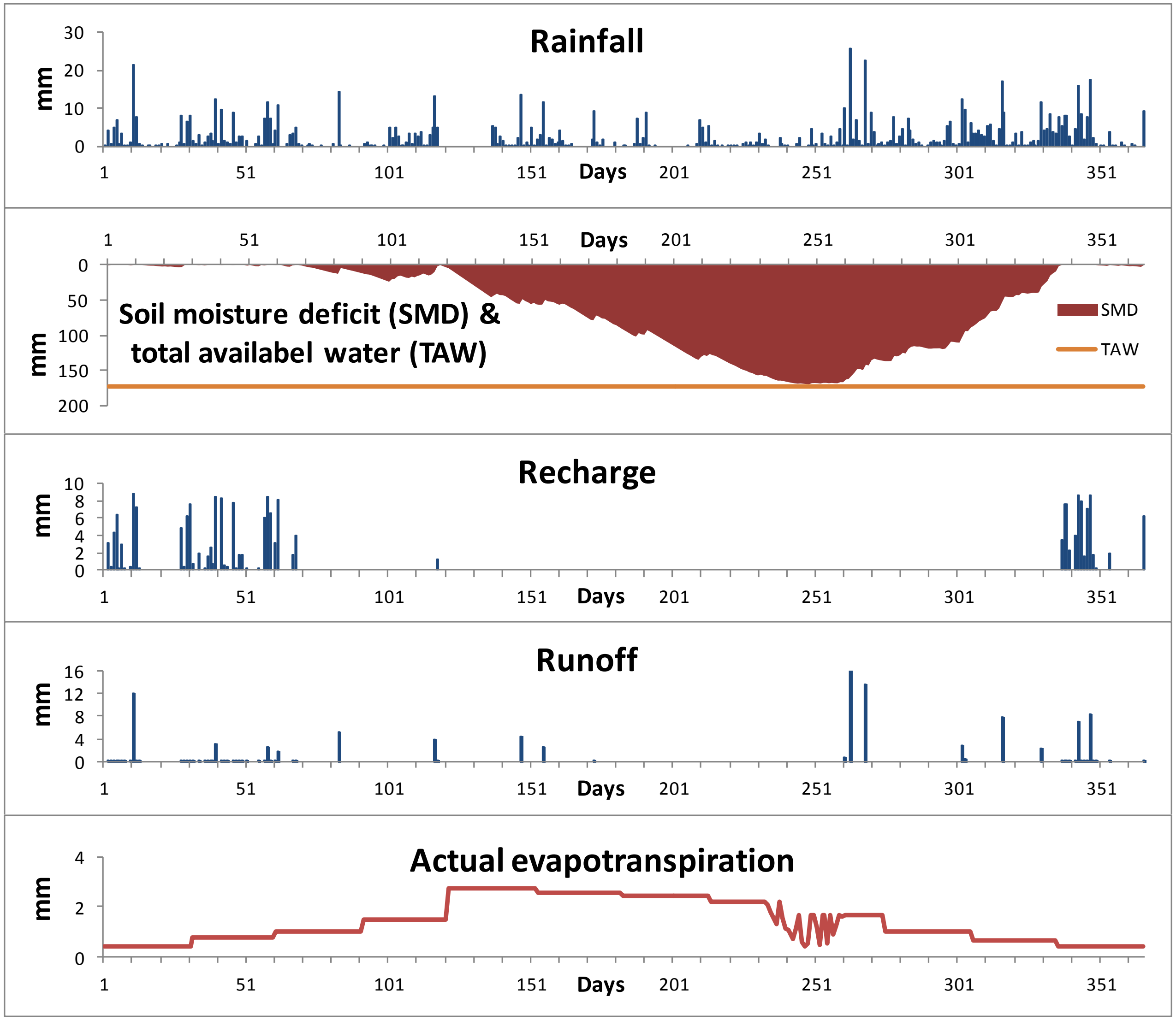
Ormiston Mill
NSE: 0.74
Observed surface flow
Modelled surface flow
Surface flow (ML/day)
0
5000
10000
15000
20000
25000
30000
Date
01/1991
02/1991
03/1991
04/1991
05/1991
06/1991
07/1991
08/1991
09/1991
10/1991
11/1991
12/1991
01/1992
02/1992
03/1992
04/1992
05/1992
06/1992
07/1992
08/1992
09/1992
10/1992
11/1992
12/1992

Results

- Daily recharge
- Yearly recharge
- Long-term-average recharge



Results



The major soil water processes of 1994 for a location in the case study area

Whilst recharge occurs generally during the winter when plant growth is minimal in a temperate climate, the recharge in semi-arid climate is generated in a distinctive rainy season when the main crop growth occurs (Rushton et al., 2006).

Discussion

- This can be a starting point to study the impacts of climate and land-cover changes on national recharge and hence groundwater for Great Britain;
- The method/model can be transferred to other areas for recharge & runoff modelling at the catchment or regional scale;
- The suitability of this method in arid and semi-arid area needs to be tested;
- SLiM can be used to build up a rainfall-recharge-runoff model quickly with readily available datasets.
- SLiM, a simple method, can be further developed to introduce more complexities.

Conclusion

- This national model can produce sensible results;
- Recharge datasets simulated can be fed into other groundwater models, such as groundwater flow, nitrate time-bomb and groundwater pollution risk assessment models; and
- This simple method can be integrated into other environmental models.

Thank you

For your attention!